Local chronicles reveal the effect of anthropogenic and climatic impacts on local extinctions of Chinese pangolins in China

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Abstract

Anthropogenic and climatic factors affect the survival of animal species. Chinese pangolins are a critically endangered species, and identifying which variables lead to local extinction events is essential for conservation management. Local chronicles in China serve as long-term monitoring data, providing a perspective to disentangle the roles of human impacts and climate changes in local extinctions. Through a generalized additive model, extinction risk assessment model and principal component analysis, we combined information from local chronicles over a period of three hundred years (1700-2000) and reconstructed environmental data to determine the causes of local extinctions of the Chinese pangolin in China. Our results showed that the extinction probability increased with population growth and climate warming. An extinction risk assessment indicated that the population and distribution range of Chinese pangolins has been persistently shrinking in response to highly intensive human activities (main cause) and climate warming. Overall, the factors that cause local extinction, intensive human interference and drastic climatic fluctuations induced by global warming, might increase the local extinction rate of Chinese pangolins. Approximately 25% of extant Chinese pangolins are confronted with a notable extinction risk (0.36[?]extinction probability[?]0.93), specifically those distributed in Southeast China, including Guangdong, Jiangxi, Zhejiang, Hunan, Fujian, Jiangsu and Taiwan Provinces. To rescue this endangered species, we suggest strengthening field investigations, identifying the exact distribution range and population density of Chinese pangolins and further optimizing the network of nature reserves to improve conservation coverage on the territory scale. Conservation practices that concentrate on the viability assessment of scattered populations could lead to the successful restoration of the Chinese pangolin population.

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Abstract

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Keywords

pangolin conservation, extinction risk assessment, historical data, climate change, human interference

Introduction

Accelerated anthropogenic impacts and fluctuating climate change are widely considered to be responsible for the continuous loss of biodiversity (Dirzo et al., 2014; Koch et al., 2006). Over the past three centuries, many mammals in China have exhibited distinct population declines and shrinking distribution ranges, likely associated with increasing human populations and climate fluctuations (Wan et al., 2019). Habitat loss, population decline or displacement, and even local extinction of wildlife are caused by anthropogenic factors, including overexploitation, agricultural development needs, urbanization, deforestation and human-introduced diseases (Trombulak and Frissell, 2000; Rosser and Mainka, 2002; Hill and Hamer, 2004; Smith et al., 2006; Mckee and Chambers 2011; Dirzoet et al., 2014; Menon et al., 2015; Turvey et al., 2017). Climate change, including warming, cooling and fluctuation, could influence the survival of wildlife regionally, and distribution shifts are the response that would most likely lead to local extinction (Pearson and Dawson, 2003; Koch and Barnosky, 2006; Chen et al., 2011; Hei, 2012; IPCC, 2014; Li et al., 2015). It is widely recognized that human disturbances have the greatest impact on wildlife extinction, but the contribution of climatic factors can reach up to 54% (Urban, 2015; Sahajpal and Goyal, 2018). In addition, the interaction of climate change and human interference could accelerate wildlife extinction (Wan et al., 2019). Therefore, determining which specific factors have a greater impact will influence conservation decisions.

The Chinese pangolin (*Manis pentadactyla*) is a unique, scale-covered mammal species that mainly feeds on ants and termites, playing an important role in maintaining the stability of the ecosystem (Sharma et al., 2020; Liu et al., 2020). China used to be one of the largest consumer markets of pangolins and their derivatives in Asia (Sharma et al., 2020). Scales of Chinese pangolin were used in traditional medicine, and its meat was consumed as a luxury food in China. In the past five decades, the distribution range of Chinese pangolins has been rapidly shrinking, and the population has declined by 80%-90% in several provinces of China (Challender et al., 2015, 2019). Severe hunting and poaching stress imposed by the local and international pangolin trade across its distribution range have been demonstrated to cause the accelerated decline of Chinese pangolins during this time period (Nash et al., 2016; D'Cruze et al., 2018). The government of China made positive efforts to protect this endangered species, such as upgrading Chinese pangolins from National Level II Protected Animals to Level I and removing the species from the *Chinese Pharmacopoeia* in 2020, which strengthened the conservation policy (National Forestry and Grassland Administration, 2020). Despite the enormous human influence, we still cannot ignore the negative effects of climate change on the loss and alteration of the Chinese pangolin habitat because climate change during this period was also very drastic. The average global surface temperature increased by approximately 1 °C, and extreme weather events occur more frequently than before (NOAA, 2021).

Identifying the causes of local extinction is an indispensable step in conservation practice (Mateo-Tomás and Olea, 2010). However, the quantitative relationships between local extinctions of Chinese pangolin and anthropogenic and climatic factors have not been evaluated. It is difficult to quantitatively determine which variables are the main factors due to the lack of long-term monitoring data. Local chronicles data provide insight into the roles of human impacts and climate change in causing local extinctions of Chinese pangolins. For more than 3600 years, since the Shang and Zhou dynasties, China has a long history of recording significant political and natural events. Owing to its economic value (mainly for traditional medicine or as a rare gift), unique characteristics and reactions to human activities (curling up when threatened), sightings of Chinese pangolin were likely to be recorded in historical documents. Therefore, local chronicles (from province to district), official and formal records such as *Twenty-Four Histories* , and *Comprehensive Mirror for Aid in Government* could be used to track the changes in the distribution of the Chinese pangolin. In addition, the History Database of the Global Environment (HYDE) consists of historical population estimates and land use metrics, in particular, the population count, population density, cropland coverage and the degree of grazing, which are human factors affecting the survival of wild animals. The time coverage of the HYDE database is from 10000 BC to 2016 AD. Data from 1700-2016 have a 10-year resolution, and the spatial resolution reaches 0.5×0.5 arc degrees (approximately 50×50 km^2) (Goldewijk et al., 2017). Weather data reconstructed from the records of $\delta^{18}O$ in ice cores in the Himalayas and tree rings worldwide exhibit a highly significant correlation with the average temperature and can be used as a metric to assess climate change in the Northern Hemisphere (Zhao et al., 2014; Shi et al., 2015). Benefiting from the unremitting development and updating of historical databases of the global environmental data (anthropic and climatic) and combining local chronicles, we have an opportunity to identify the causes of local extinctions of the Chinese pangolin to inform conservation actions that target the species (Wen 2009).

Therefore, we used local chronicles of the Chinese pangolin in China and combined them with quantified anthropogenic stressors (represented by population counts, population density, cropland coverage and grazing) and temperature variations (represented by holistic temperature and regional temperature) through a generalized additive model (GAM) to determine key causes of local extinctions in 1700-2000 (Wan et al., 2019). Then, we lowered the temporal scale and built an extinction risk model estimated by the maximum entropy algorithm to identify which variables contributed to the extinction events in 1970-2000, relying on much more accurate and detailed environmental data (RoDder et al., 2009; Benito et al., 2009). Through principal component analysis, we further determined the degree of variation of those variables. Finally, we used rescue information from the wildlife rescue departments and Global Biodiversity Information Facility (GBIF) database from 2000-2020 to evaluate the threatened status of extant Chinese pangolin populations in China. Learning from history, our research can have implications for the conservation practices to protect Chinese pangolins in China now and in the future.

Materials and methods

Establishment of Spatial-time GAMs

We obtained data regarding the historical distribution of Chinese pangolins from the compendium of *The Distributions and Changes of Rare Wild Animals in China,* in which the occurrence times and locations of the species were recorded from standard histories and local gazetteers, as well as physical remains discovered in 1700-2000 (Wen 2009). The approach to the inclusion of historical literature records in the compendium was conservative; records lacking other supporting observations were excluded, and only confirmed records were included (Wen 2009). We extracted information on Chinese pangolin occurrences (year and location) from the compendium and then reconstructed the longitude and latitude of those locations (Liang 1980).

To track the historical extinction events of the Chinese pangolin, we divided China into 4345 square grids (50 km^2 ×50 km^2) and the full study period into ten 30-year periods (analyses based on 50-year periods were also conducted, but no significant results were obtained). For each grid, only presence and absence for each sampling year of were populated; specifically, if the Chinese pangolin was present in one 30-year period in a coded grid, we recorded this as event as 0 (presence) and if the occurrence of the species was not detected again in this grid, the next 30-year period would be recorded as 1 (absence). The above process represents a complete extinction event. After data verification, we detected 314 local extinction events of Chinese pangolins across China in 1700-2000.

Five anthropogenic variables, two climatic variables and their coordinates were used to establish GAMs. The anthropogenic factors used in the analysis were as follows: population density, defined as the number of persons per square kilometer per grid cell in a period from HYDE (version 3.2.1); cropland, defined as the proportion of cropland coverage in each grid; population counts, defined as the number of inhabitants in each grid; grazing, defined as the land use for grazing in each grid; and population, defined as the total population in China (download from*https://dataportaal.pbl.nl/downloads/HYDE/HYDE3.2/)*(Goldewijk et al. 2017). Temperature was represented by oxygen isotopes ($\delta^{18}O$) of ice cores in the Tibetan Plateau was used as a proxy for holistic temperature fluctuation in China (download from*http://www.tpdc.ac.cn/zh-hans/*) (Zhao et al., 2014). Regional temperature (5°×5° resolution) was represented by the average temperature during the Asian summer season (June to August) based on 357 publicly available proxy climate datasets (mainly tree ring sequence) from the World Data Center for Paleoclimatology archives. These data were used as the thermal proxy for regional temperature (download from*https://www.ncdc.noaa.gov/paleo-search/study/18635*) (Shi et al., 2015). From 1700 AD to 2000 AD, the HYDE and climate data had a 10-year resolution. We used the average to represent the entire 30-year period.

The GAM algorithm was used to model the associations of population density, cropland coverage, population count, grazing, population, temperature and regional temperature with local extinctions of the Chinese pangolin. Based on the results of the Pearson correlation test, we found that temperature and population were highly correlated (r>0.7), and those two variables both exhibited a high correlation with local extinctions. However, significant effects of population density, cropland, grazing and regional temperature on local extinctions of Chinese pangolin were not detected with this method. Therefore, to avoid information loss, we established two categories of GAMs. Temperature and population were taken as the main variables of the regression models.

Extinction risk assessment

Population growth and temperature increases in China have been highly correlated in the last few hundred years, which leads to uncertainty regarding which variable plays a stronger role in local extinctions. In total, 604 occurrence records (87% of the historical observations) of Chinese pangolin were documented in 1970-2000 across China, and more detailed climatic data are available for this period. Therefore, we lowered the timescale and combined 19 climatic variables, anthropogenic variables from HYDE, elevation and identified extinction records of Chinese pangolin to construct a model to assess extinction risk with MaxEnt. We compared those occurrences with the current distribution range of Chinese pangolins assessed by the IUCN expert group and identified 94 occurrences outside the distribution area (IUCN, 2019; Fig. 2). We collected 162 rescue and observation records of Chinese pangolins during 2000-2020 from the wildlife recuse departments, news reports and GBIF database in China. We set up circular buffer zones (r=50 km) according to extant occurrences of Chinese pangolin to exclude the potential distribution area (Fig. 2). Considering the rapid development of wildlife monitoring technology and emphasis on biodiversity conservation of the Chinese government, 220 occurrences out of buffer zones were supposed to be extinct (Fig. 2). In total, 314 occurrence records out of distribution range and buffer zones were considered extinction locations (Fig. 2). Those occurrences were dispersed (no highly spatial autocorrelation) based on the analysis of Ripley's K function. The elevation data were derived from the SRTM. Higher-resolution and multidimensional climate data from 1970-2000 were available from WorldClim (download from*https://worldclim.org/*). These biological variables are related to various aspects of temperature and precipitation affecting the geographic distribution of Chinese pangolins and their prey (mainly ants and termites).

The resolution of the environmental variables was uniform at 5 arc minutes, and each grid retained only one occurrence record. We input extinction records and environmental variables into MaxEnt (version 3.4.1) (Phillips et al., 2006) and ran the Model 25 iterations (preexperiment) to exclude insignificant variables with 0% contribution and 0 permutation importance value. To avoid multicollinearity, we calculated the Pearson correlation coefficient (r) between variables; when r >0.7, the variable with the lower contribution rate was discarded. Finally, eight variables, including population density, elevation, cropland, grazing, temperature seasonality (bio4), mean temperature of the driest quarter (bio9), precipitation seasonality (bio15) and precipitation of the warmest quarter (bio19), were used to construct the model.

We ran the Algorithm 100 times, and the average of the predicted results was output in logistic. Maximum training sensitivity plus specificity was used as the threshold value to distinguish extinction, and Nature Breaks methods were used to further assess the levels of extinction risk. Finally, we extracted the extinction risk of extant populations of Chinese pangolins according to the risk map.

PCA of local extinction events

Through principal component analysis (PCA), we estimated the degree of variation in the contributory variables. In the above, we identified eight variables that contributed to local extinction (contribution rate >1), and we used the sampling method in GIS (version 10.4) to extract the information of associated environmental variables, including population count, elevation, cropland, grazing, bio4, bio9, bio15 and bio19, of the 314 extinction records in 1970-2000 to analyze the principal components of local extinction events of Chinese pangolin.

Result

Effects of anthropic and climatic factors

Through spatial-temporal GAM analysis, we found that population and temperature had significantly positive correlations with the local extinctions of Chinese pangolin in 1700-2000 across China (Table 1). The extinction probability of the Chinese pangolin increased with increasing temperature and total population growth (Fig. 1). In addition, geographic distribution was also associated with local extinctions, and Chinese pangolins were more likely to go extinct at high longitudes and latitudes in China (Fig. 1). However, the effects of population density, cropland, grazing and regional temperature on local extinctions of Chinese pangolin were not detected through this method (Table 1). The opinion that climate change and human interference affected the survival and geographical distribution of Chinese pangolins was confirmed. However, we could still not determine which variable played a pivotal role in local extinctions of Chinese pangolin according to the regression models. Total population and average temperature of China both present increasing trends. The difference is the temperature are much more fluctuant (Fig.S1, Fig.S2).

Chinese pangolin extinction-risk model

We successfully modeled the extinction risk of the Chinese pangolin across China with MaxEnt from 1970-2000 (Fig. 3). The average test AUC of 100 replicate runs was 0.935, and the standard deviation was 0.007. The prediction results had a satisfactory reference value. The population count gained a 68% contribution rate of the model: bio19 contributed 11%, bio4 contributed 6.9% and elevation contributed 5.3% (others included bio9 [3.1%], bio15 [2.1%], cropland [1.9%] and grazing [1.6%]). The extinction risk ranged from 0 to 0.93. The marginal response curve of a single variable indicated that as the population count increased, the extinction risk was elevated exponentially. When the population count reached approximately 7500 persons each grid (100 km^2), the extinction risk remained almost unchanged (supersaturated status). The extinction risk first increased and then decreased with increasing precipitation in the warmest quarter and seasonal changes in temperature and elevation. The extinction risk model indicated that anthropogenic variables could be the principal causes of local extinctions of Chinese pangolins, followed by climatic variables.

Variation in environmental variables

Through PCA, we analyzed the environmental information of the 314 extinction occurrences of Chinese pangolins out of the distribution range in 1970-2000 across China. After dimension reduction, Comp. 1 represented the precipitation of the coldest quarter (bio19, positive correlation), elevation and seasonality of precipitation (elevation and bio15, negative correlation). Comp. 2 represents the seasonality of temperature (bio4, positive correlation) and mean temperature of the driest quarter (bio9, negative correlation). Comp. 3 represents population counts (positive correlation) and grazing (negative correlation). The first two principal components accounted for 57.92% of the variance contribution rate (Fig. 4). Comp. 3 contributed 15.68%, and the first three contributed 73.6% of the variance. The PCA results indicated that climatic factors had a greater degree of variation than anthropic variables in extinction events.

Extinction-risk assessment of extant populations

Through the sampling method in GIS, we extracted the extinction probability of extant distribution sites according to the extinction-risk map of Chinese pangolin. The results showed that 48.77% of extant distribution sites were confronted with no extinction risk (extinction probability < 0.2), 25.93% were at low extinction risk [0.2, 0.36), 11.73% were at moderate extinction risk [0.36, 0.55) and 13.41% were at high extinction risk [0.55, 0.93) (Fig. 3, Fig. 5). In total, a quarter of extant populations were at notable (moderate and high) extinction risk. Those sites in moderate and high extinction risk were dispersedly distributed in southeast China, including Guangdong, Jiangxi, Zhejiang, Hunan, Fujian, Jiangsu Province and Taiwan (Fig. 5). Fifteen distribution sites were confronted with high extinction risk (total 41) spread over Guangdong Province, eight were in Jiangxi and Taiwan Provinces, and five were in Zhejiang Province (Fig. 5).

Discussion

Combining multiple perspectives, scales and methods, local chronicles revealed that anthropic and climate variables were significantly associated with local extinctions of Chinese pangolin in China. In summary, the substrates that caused extinction were intensive human interference, and drastic climatic fluctuations induced by global warming accelerated the extinction process. Hunting, farming and grazing conducted by humans caused population decline and extinction of wildlife. The anthropic pressure to which Chinese pangolins were exposed might have exceeded their tolerance threshold. Through the interaction of human and climate disturbances, more drastic climate change in recent years has accelerated the extinction rate of Chinese pangolins (Li et al., 2018). Our results implied that human disturbance and climate change codetermined the current distribution of Chinese pangolins. The population and distribution range of the Chinese pangolin will continue to shrink with highly intensive human activities and drastic climate change.

Local chronicles served as long-term monitoring data and provided important insights revealing the association of anthropic and climatic variables with the local extinctions of the Chinese pangolin. The Chinese pangolin was once a widely distributed species in China and is now only distributed in provinces south of Yangtze, including Fujian, Guangdong, Guangxi, Yunnan, Guizhou, Hunan, Hainan and Taiwan (Allen and Coolidge, 1940; Jiang, 2015). From the 1960s, the population of the Chinese pangolin decreased by 88.88%-94.12% and disappeared from more than half of its distribution range in southern China (Wu et al., 2004). Historical data have helped identify the driving forces of local extinctions in the long term and have contributed to the generation of efficient conservation strategies for Chinese pangolins. However, due to the limitations of historical environmental data, hunting and poaching pressures could not be accurately assessed because measurements of population density and counts do not exhibit correlation with them in highly urbanized areas (Nash et al., 2016). This could be the reason why GAMs were unable to detect the significant influence of population density and count.

Along with population growth, trade and consumer demand have become major threats to the survival of Chinese pangolins and can be represented by the total population count (Challender et al., 2015). Pangolin scales were thought to cure evil sores, malaria, and mastopathy according to traditional Chinese medicine (e.g. Compendium of Materia Medica) and pangolin meat was considered a luxury food item (Challender et al.,2015). In the past, China was one of the largest consumer markets in Southeast Asia, and a growing population has led to increasing demands for pangolin products. In addition, population growth exacerbates hunting, poaching, and land utilization, which directly leads to the decline of pangolin populations, habitat loss and fragmentation, followed by local extinctions (Turvey et al., 2017).

Based on the results of the principal component analysis, the variation in climate data was much greater than that in anthropogenic data, implying that the Chinese pangolin is more easily affected by climate change. The Chinese pangolin is a homotherm and accelerated global warming and temperature fluctuations may affect them negatively. First, the density of Chinese pangolins may change at given locations, and the ranges of species may shift either poleward or up in elevation as species move to occupy areas with climates within their metabolic temperature tolerances. Second, because many natural history traits of species are triggered by temperature-related cues, changes could occur in the timing of events (phenology), such as migration and breeding. The synergism of rapid temperature rises and human stressors, in particular habitat destruction, could easily disrupt the connectedness among species and lead to a reformulation of species communities, reflecting differential changes in species, and to numerous extirpations and possibly extinctions (Root et al., 2003). In addition, global warming increases the probability of extreme weather and wildlife diseases. East Asia is subject to increased warm and dry extremes, and southeast Asia experiences a higher probability of extreme rainfall in spring (Lee et al., 2012; Thirumalai et al., 2017). The risk of contracting diseases (especially vector-borne diseases) both in humans and animals increases as a result of global warming. Species extinctions may be due to changes in habitats or the transport of livestock which facilitates the movement of viruses and arthropods (especially ticks) from one place to another (Black et al., 2008; Dhama et al., 2013).

Their scattered distribution implies that the conservation practices of Chinese pangolins must depend on the efforts of local governments. Chinese pangolin populations with a high risk of extinction are spread over more than six provinces in China (Fig. 4), and 36.59% of high-risk populations are distributed in Guangdong, which is one of the most developed provinces in China. Therefore, the challenge is how to coordinate wildlife conservation and local economic development in Guangdong. Given this, we suggest strengthening population field investigations and accurately identifying the distribution range of Chinese pangolins. Further efforts to optimize the network of nature reserves to improve the conservation coverage of Chinese pangolins from the perspective of territory are required because the species has not received enough conservation resources in the past. An off-site conservation strategy is another workable solution to overcome conflicts between local economic development and small populations of Chinese pangolins (Vitt and Havens, 2004).

China has been strengthening its conservation policy for the Chinese pangolin. All illegal wildlife trade has been strictly banned to eliminate the excessive consumption of wildlife and ensure ecological security (NPC, 2020). In addition, the Chinese government strengthened the management of medicinal animal products, and pangolin scales were removed from the Chinese pharmacopoeia in 2020. Moreover, the Chinese government upgraded the designation of the Chinese pangolin to first-class national protected animals in the same year (National Forestry and Grassland Administration, 2020), indicating that this species and its habitat would receive stricter protection after the prohibition of the wildlife trade.

Future conservation practices may need to focus more attention on the assessment of small population viability and the subsequent population restoration. Excessive human exploitation and utilization of land resources lead to the fragmentation of the habitat of Chinese pangolins and suitable habitat patches and even national nature reserves with defined protection objectives usually present as “isolated islands” in a world dominated by human activities. Small populations are less stable and more susceptible to inbreeding depression and outside interference (Seth et al., 2021). Chinese pangolins are widely distributed, and it is feasible to establish ecological corridors between habitat patches that are close in proximity. However, species recovery among long-distance and isolated patches requires appropriate human intervention to save local populations. Artificial breeding, rewild and reintroduction are reasonable methods to guard against the extinction of small populations (Kuehler et al., 2000). In addition, based on an empirical analysis, the distribution mode of extant Chinese pangolins did not show a typical avoidance strategy for human settlements (Zhang et al., 2021; Wang et al., 2020). Residential and rural areas that overlap with pangolin populations should be targeted for efforts to improve awareness of the benefits of wildlife conservation (Zhang et al., 2021).

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Conflict of interest

None.

Author contribution statement

All authors participated in the design of the research. Haiyang Gao wrote the paper. Yan Hua revised the paper. Hongliang Dou, Shichao Wei, Song Sun and Yulin Zhang participated in data collation and analysis.

Data availability

The data that support the findings of this study are available in the supplementary materials.

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Table 1 Correlation coefficient and significance testing of the established GAMs. n=790.

	Variables	Coefficients	P value
Model1	Temperature	6.454***	<0.0001
	Lon., Lat. Popd Popc Corpland Grazing RegionalTemp.	2.137* 4.507 2.359 3.488 8.127 2.284	0.0398 0.5498
Model2	Population	7.713***	0.0018
	Lon., Lat. Popd. Popc. Corpland Grazing RegionalTemp.	2.111* 1.463 3.170 9.029 2.592 7.649	0.0497 0.7228

Lon., longitude; Lat., latitude; Popd., population density; Popc., population count; *p<0.05, *** p<0.001.

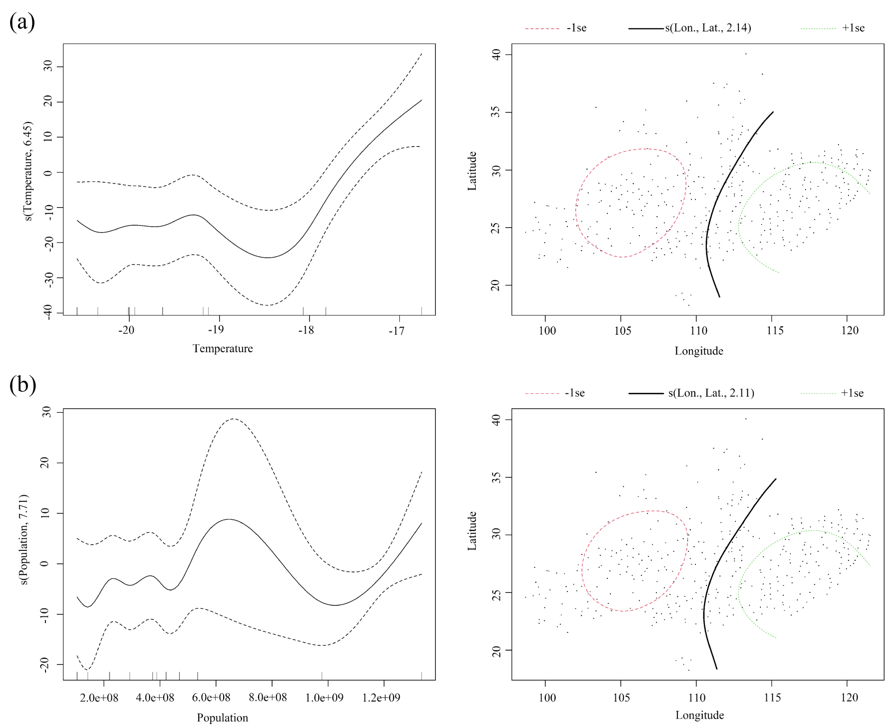
Fig. 1. Relationship between local extinctions and temperature, population, geographical distribution from AD1700 to 2000. The first set of variables are temperature and geographical distribution (a). The second set includes the population and geographical distribution (b). Local extinctions are dichotomous events (0,1), and temperate is represented by oxygen isotopes.

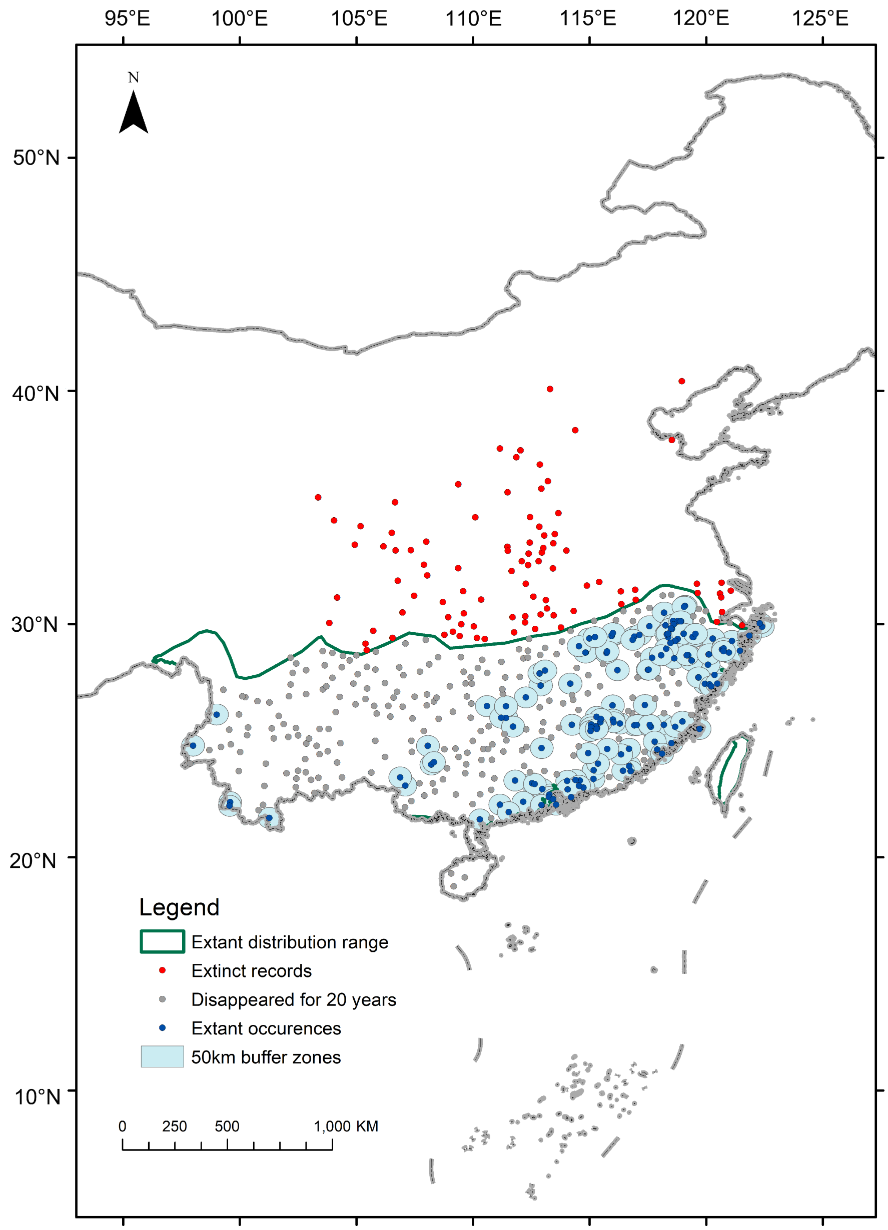
Fig. 2. Extant occurrence records, distribution range and extinct records of Chinese pangolins across China. We used 50 km buffer zones to exclude extant occurrence records and identified extinct records.

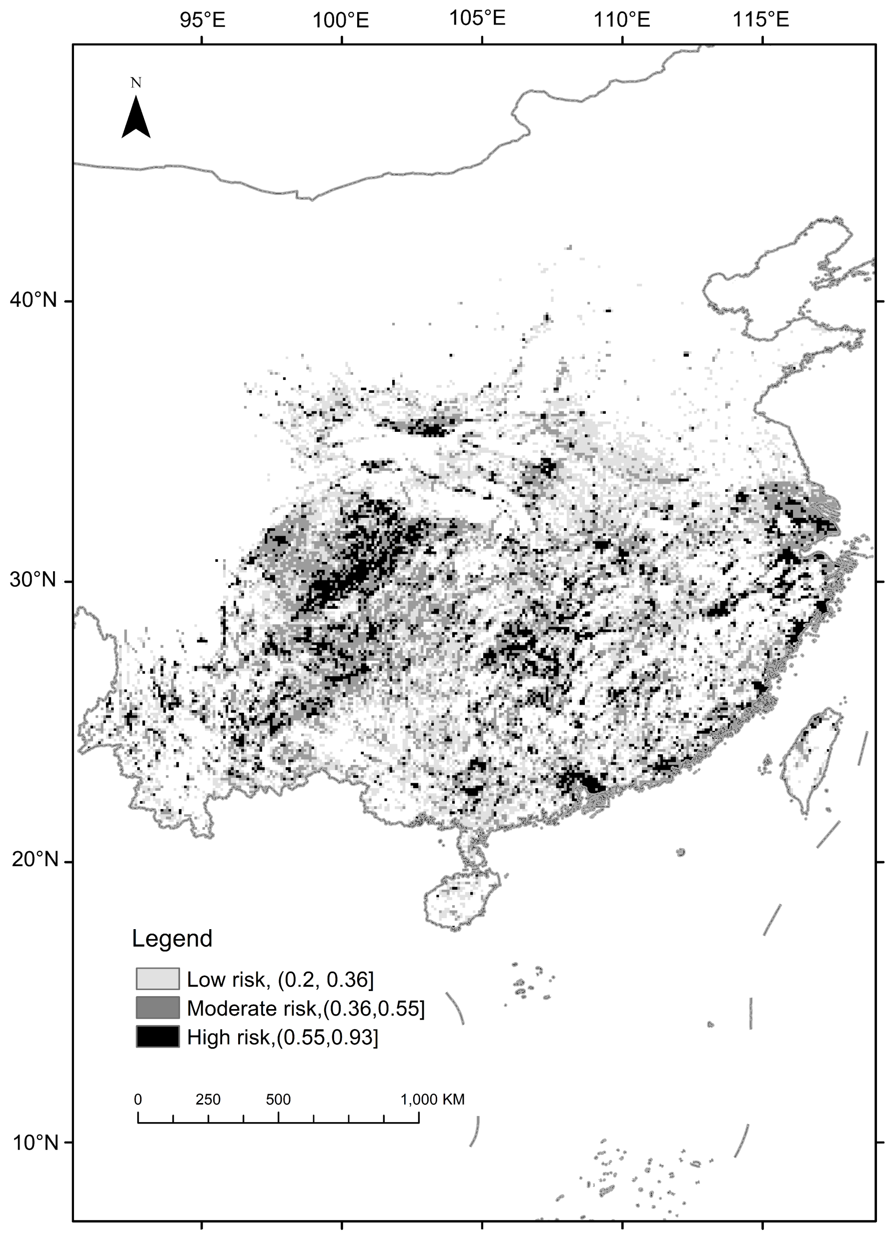
Fig. 3. Extinction-risk assessment of Chinese pangolins across China predicted by MaxEnt during 1970-2000.

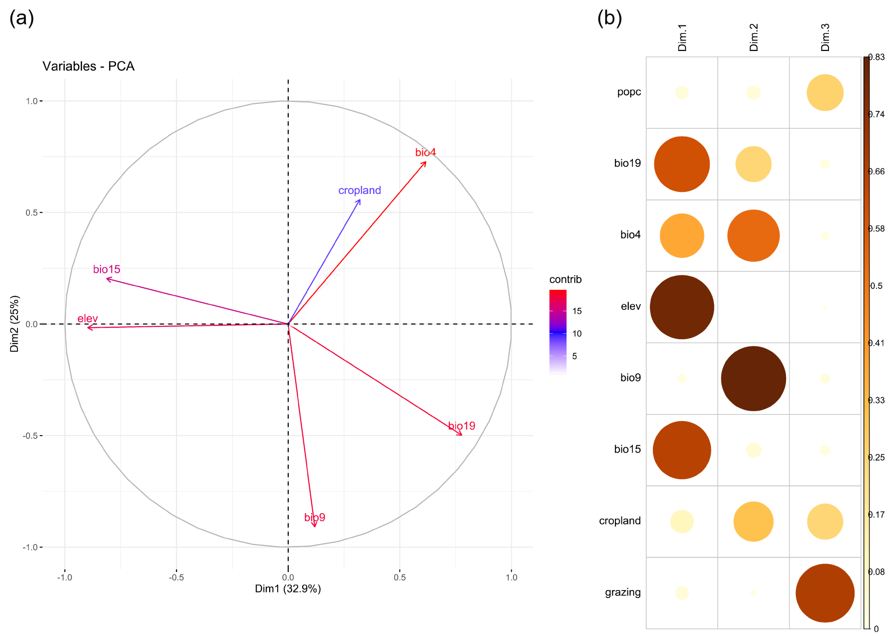
Fig. 4. Variable contribution rate of the first two principal components (a) and representation of principal components to variables (b). There were 314 extinction events identified. Through PCA, variances of the first three principal components were greater than 1, and the three together accounted for 79.64% of the variance.

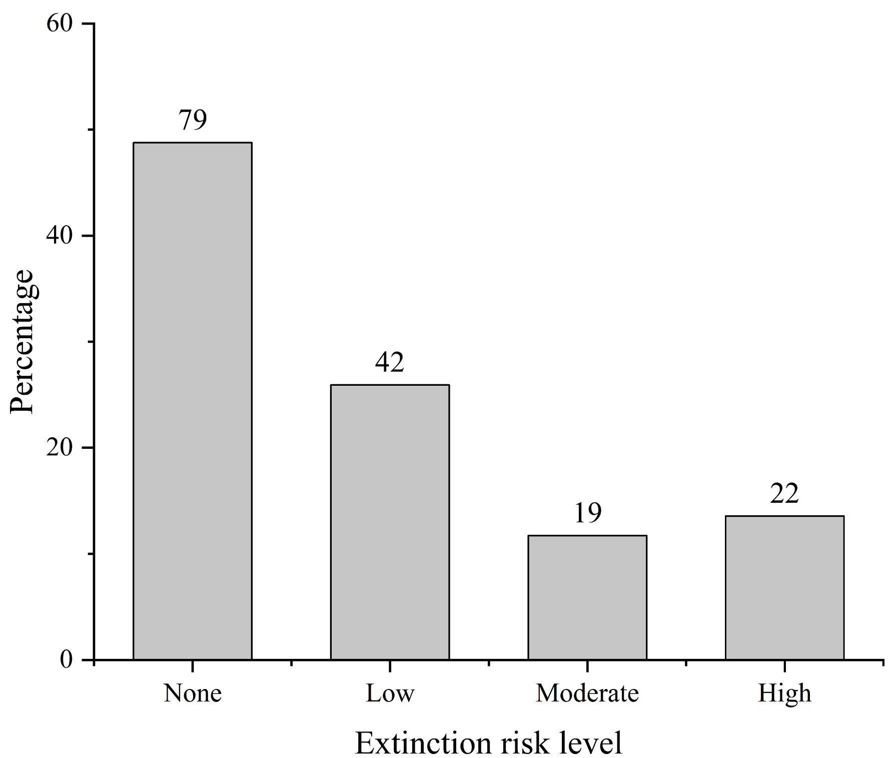
Fig. 5. Percentage of extant Chinese pangolin populations confronting moderate and high extinction risk.




95°E
100°E
105°E
110°E
115°E
120°E
125°E
50°N
40°N
30°N
20°N
10°N
N
Legend
Extant distribution range
Extinct records
Disappeared for 20 years
Extant occurences
50km buffer zones
0
250
500
1,000 KM


95°E
100°E
105°E
110°E
115°E
40°N
30°N
20°N
10°N
N
Legend
Low risk, (0.2, 0.36]
Moderate risk,(0.36,0.55]
High risk,(0.55,0.93]
0
250
500
1,000 KM


(a)
Variables - PCA
bio4
cropland
bio15
elev
bio19
bio9
Dim1 (32.9%)
Dim2 (25%)
contrib
15
10
5
(b)
Dim.1
Dim.2
Dim.3
popc
bio19
bio4
elev
bio9
bio15
cropland
grazing
0.83
0.74
0.66
0.58
0.5
0.41
0.33
0.25
0.17
0.08
0


Percentage
60
40
20
0
79
42
19
22
None
Low
Moderate
High
Extinction risk level